

DIMENSIONS

Measuring LNG
-A Limited
Resource



DIMENSIONS

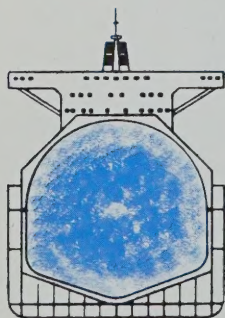
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Cover: With the increasing emphasis on conserving energy, every bit of fuel becomes more precious. Scientists at NBS are working to establish measurement methods that will assure accurate custody transfer of liquefied natural gas. See article on page 171.

U.S. DEPARTMENT OF COMMERCE Frederick B. Dent, Secretary . .

Betsy Ancker-Johnson
Assistant Secretary
for Science and Technology

NATIONAL BUREAU OF STANDARDS
Richard W. Roberts, Director

Prepared by the NBS Office of
Information Activities
Washington, D.C. 20234
William E. Small, Chief

Richard S. Franzen,
Chief, Editorial Section

Sharon A. Washburn,
Managing Editor

Contributing Editors
L. Kenneth Armstrong, Robert J.
Griffin, Jr., Kent T. Higgins, Madeleine
Jacobs, Juli Kelley, Stanley
Lichtenstein, Frederick P. McGehan,
R. David Orr, Alvin L. Rasmussen,
Arthur Schach, Collier N. Smith

Visual Editor
Charles Messina, Jr.



The National Bureau of Standards serves as a focal point in the Federal Government for assuring maximum application of the physical and engineering sciences to the advancement of technology in industry and commerce. For this purpose, the Bureau is organized as follows:

The Institute for Basic Standards
The Institute for Materials Research
The Institute for Applied Technology
The Institute for Computer Sciences and Technology
Center for Radiation Research
Center for Building Technology
Center for Consumer Product Safety

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ALTHOUGH our Nation's shortages of petroleum products have subsided, the winter months may again foretell a crisis—the lack of fuels for heating.

A solution to meet increased demands has been to import more natural gas. Pipelines from Canada and Mexico provide small amounts, but pipelines across oceans to major sources are impossible. An alternate method involves importing natural gas as a liquid called liquefied natural gas (LNG). Annually, the United States produces over 623 billion cubic meters (22 trillion cubic feet) of natural gas, imports about 30 billion cubic meters and uses 97 percent of it as a fuel.

Variations of Natural Gas

Depending on the source, natural gas is basically composed of gaseous methane, usually 80 to 99 percent. Other gaseous components may include carbon monoxide, sulfur compounds, other heavier hydrocarbons and inert gases. Each source of natural gas differs in density and heat output. Heat output is expressed as

joules (J) or British Thermal Units (BTU's). Natural gas suppliers must constantly adjust the composition of their dispensed gas to attain a standard heat output of about 38.54 million joules per cubic meter or 1,035 BTU's for every cubic foot supplied.

NBS & LNG

A group of scientists, located at the National Bureau of Standards, Boulder, Colo., laboratories, are actively involved in researching the science of cryogenics. This science deals with the physics and engineering of materials cooled to temperatures hundreds of degrees below zero Fahrenheit. LNG, because of its mixture of low-boiling-point temperature fluids, falls within the temperature range of this science. A typical natural gas mixture liquefies at

temperatures below 190 K (-117°F), boils very near 113 K (-256°F) and freezes near 90 K (-297°F).

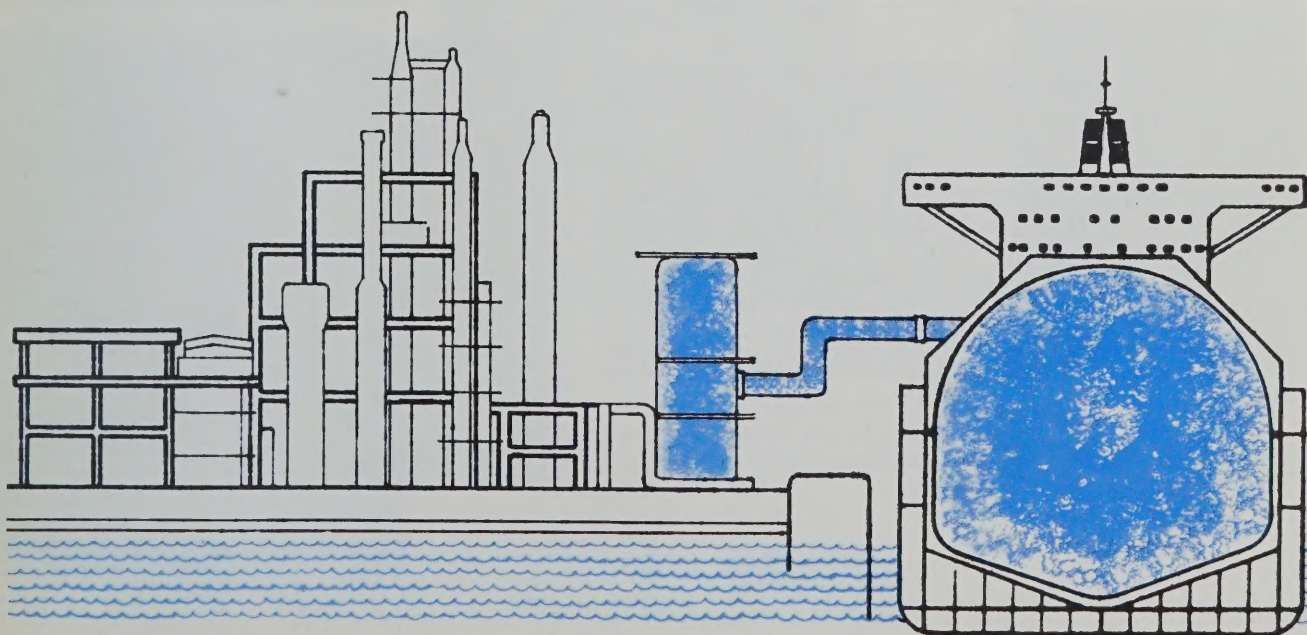
Studies of the mechanical properties of solid metals cooled to cryogenic temperatures are also underway in Boulder. Of particular interest to the cryogenics scientist is the growth rate of cracks in steel and nickel alloy metals due to fatigue. These metals are presently used in LNG storage tanks and tanker ships. These physical characteristics must be known, and soon, due to the projected daily storage and transfer of LNG ship-load quantities exceeding 100,000 cubic meters.

Several NBS cryogenics scientists, working under contracts from trade associations and Federal agencies, are studying ways to standardize the commercial measurements of LNG.

turn page

Making the Most of a Limited Resource

NBS Measures and Defines LNG



LNG continued

Although LNG is currently being shipped and traded daily in up to 72,000-cubic-meter quantities all over the world, custody transfer of this valuable liquid from supplier to buyer varies due to unproven measurement methods. A cubic meter of LNG can be regasified back into about 600 cubic meters (21,000 cubic feet) of natural gas. A tanker's 72,000-cubic-meter LNG cargo can heat 10,000 average American homes for 1 year. Currently, over 25 tanker ships capable of carrying 125,000 cubic meters of LNG (33 million gallons) or more are ordered or under construction. Potential measurement errors must be defined now so the buyer and seller can equally understand all aspects of a transaction. And errors are common due to the many different compositions of LNG, the liquid's continual change during transportation and storage because of selective vaporization and lack of control for many of the ill-defined and numerous measurement elements.

To accomplish commerce exchange agreements, a mutually recognized measurement process must

be developed and internationally agreed upon by seller and buyer. Such a process would then be used throughout the life of an exchange contract.

Two measurement methods are under consideration at NBS. One uses the LNG tanker ship as a calibration tank or bucket, determining the total mass on- or off-loaded by measuring the LNG volume and combining this with a density measurement. The second method determines the total amount of fluid which passes through the fill or discharge loading pipelines.

Necessary elements needed to conduct either of these measurement processes include determining the volume of the ship, the density of the LNG mixture, the sampling of the mixture, the analysis of the components and establishment of the total heating value of the mass of LNG removed from the ship. In a nutshell, the use of LNG poses many problems.

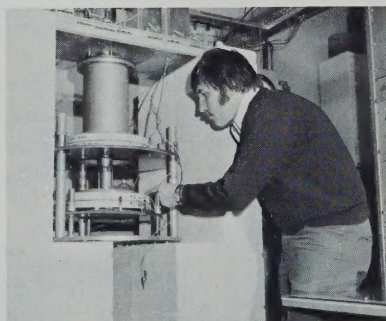
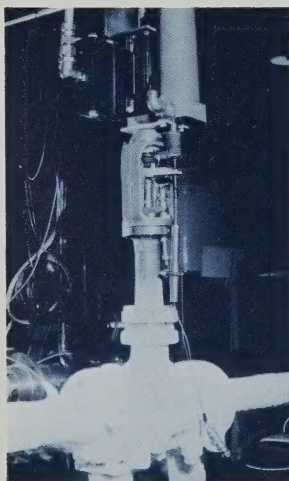
(Left.) Flow rate of pure liquid nitrogen is analyzed with meters such as this one.

(Center.) Dr. William Haynes of the NBS Cryogenics Division uses a magnetic densimeter to determine precisely the temperature of a LNG sample.

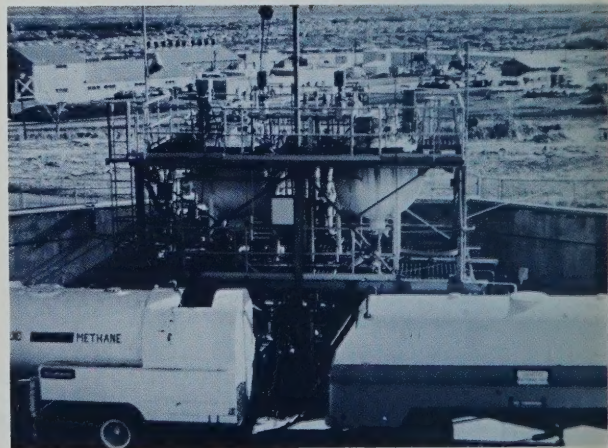
LNG Thermophysical Characteristics

The thermophysical properties of methane and LNG mixtures must be known before one can design liquefaction, storage and transportation equipment and processes. Scant physical and thermodynamic properties data are known for pure components such as methane, ethane, propane, iso-butane and normal butane when liquefied. LNG properties data are even less known due to the liquid mixture's many components. NBS recently produced accurate tables, interpolation functions and computer programs which permit the determination of densities, compressibilities and thermodynamic properties of pure gaseous and liquid methane. Similar work on ethane is underway. Phase equilibrium properties research involving measurements of methane mixed with argon and nitrogen is also being conducted in Boulder. This work aids in the development of fundamental understanding of liquid mixtures analogous to LNG at low temperatures.

Another NBS project is providing accurate density measurements for saturated liquid methane, ethane, propane, butanes, nitrogen and their mixtures. The culmination of this re-



(Right.) The volume and mass flow rates of LNG are measured at the NBS outdoor cryogenic flow facility.



search will result in a proven method to calculate saturated liquid densities of LNG mixtures with an accuracy of 0.1 percent or better. Data will primarily deal with methane-rich liquid mixtures in the temperature range from 110 to 140 K.

Volume and Mass Measurements

The metrology problems of LNG are also under study at NBS. Recent work has involved ways of calibrating commercially available flowmeters which measure the volume and mass flow rates of LNG. To accomplish this work, a special outdoor facility at the Boulder laboratories is used. This facility consists of two 1.1-cubic-meter (300-gallon) cryogenic tanks connected with vacuum insulated pipes and a circulating pump. A flow loop assembly exists between the tanks, allowing a quantity measurement of a fluid as it passes through a flowmeter. This is done by dynamic weighing of the liquid in one of the 300-gallon storage tanks. Liquid flow rates tested have ranged from 114 liters to over 750 liters (30–200 gallons) per minute through a 5-centimeter (2-inch) line. Additional gauging instruments are involved in these metrology measurements. Measurements include temperature, density and liquid level. Several of these sensor devices were previously developed for NASA space exploration programs.

Data obtained from present flowmeter tests are projected to aid in selecting a meter capable of providing a precision of less than ± 0.5 percent when scaled to 35.6- to 91.4-centimeter (14–36-inch) pipes sizes used to transfer LNG from tankers to storage facilities.

Literature Search Centers

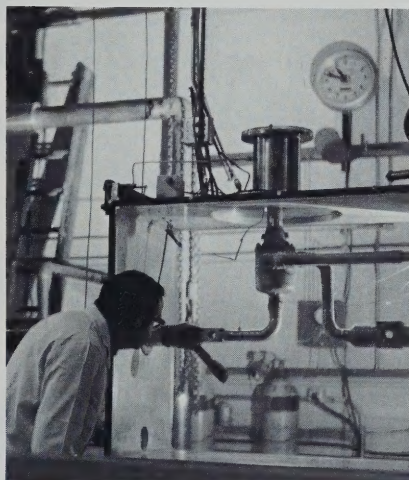
A cryogenic data information center with a computerized storage and retrieval system is also maintained at the Boulder facility. This center was established at Boulder in 1958. Scientists are kept abreast with worldwide cryogenic developments through the NBS Current Awareness Service's weekly publication. Developments, reported in 200 technical and secondary publications, are listed by the service.

Since 1969, a portion of the center's effort has been devoted to compiling methane and LNG related articles. The NBS Liquefied Natural Gas Quarterly averages over 300 references each issue. A few of the 25 different subject headings listed

are: thermodynamic properties of methane, liquefaction and separation, regasification, sea transportation, safety, instrumentation, economic factors, patents and energy.

Future Measurement Procedure Standards

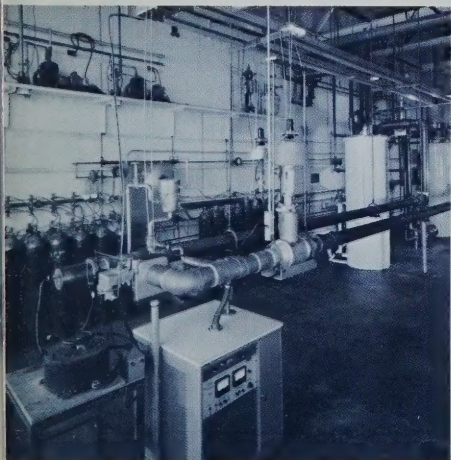
Even though the NBS Cryogenics Division scientists are many miles from ocean-going LNG tanker ships and coastal LNG storage facilities, their 20 years of activity as a group in the cryogenics field is aiding in the development of proven measurement methods for liquefied gas mixtures. Many of the questions posed are within reach of being answered. These answers may result in the establishment of future standards to be considered for adoption by the National Conference on Weights and Measures and other voluntary and statutory standards organizations. □



Dr. Douglas Mann inspects the meters in the Bureau's indoor flowmeter facility.

Flow rates for several liquefied gases commonly found in LNG mixtures have been determined at NBS' indoor flowmeter calibration facility.

NBS LNG Program Manager Dr. Douglas Mann, right, explains to Congressman Donald Brotzman the different modifications necessary to convert gasoline-burning automobiles to LNG.





*On a mesa overlooking the
NBS Boulder, Colo., laboratories,
scientists measure the power
concentration of the microwave
antenna beam.*

Getting Through with Microwaves

PERCHED upon a mesa overlooking the city of Boulder and the gentle eastward-sloping plains of Colorado is one of the world's most exact outdoor microwave antenna measurement ranges. At the base of the mesa, the National Bureau of Standards, Boulder, Colo., laboratories spread out over a 205-acre site. Scientists in NBS' Electromagnetics Division transport necessary electronic gear up to the mesa top where they use the outdoor antenna range to measure the microwave power exchanged between antennas.

On the mesa or in the laboratory, these NBS scientists dedicate themselves to measuring the microwaves radiated by antennas. But what are these microwaves and what do they do?

Microwaves Prevail

Microwaves prevail everywhere in nature. They make good terrestrial and extraterrestrial communication vehicles, generate therapeutic heat within our bodies, cook our food and, when intense, even endanger our health. They carry scientific, navigational, defense, business and entertainment information from space vehicles, satellites, airplanes, ships, automobiles, the earth and deep space. Microwaves tell us about the interworkings of the heavens and the earth's resources, send us pictures of the planets, pinpoint and guide objects and relay messages and television and radio programs over the earth and through space.

Since the 1930's microwaves have been used for radar and communications. Today messages conveyed via microwaves from St. Joseph, Mis-

souri, to Sacramento, California, take about one-hundredth of a second, a hundred-million times faster than the 10 days required by the famed Pony Express of the 1860's. Microwaves fall within the general category of electromagnetic waves and are lower in frequency and longer in wavelength than visible light and infrared radiation. They travel at the velocity of light, about 300,000,000 meters per second, penetrate and reflect upon striking objects and bend in passing through different environments. Because of their higher frequency, microwaves can carry more messages than lower frequency radio waves.

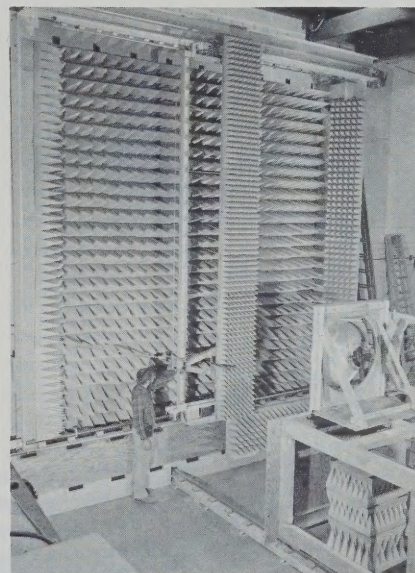
By means of special structures called antennas, microwaves are sent from transmitters or recovered into receivers. Designed for special purposes, antennas transmit microwaves in patterns or fields that vary in strength with direction and distance from the antenna. The complicated fields close to the antenna are referred to as near-fields; while the simpler fields, far away from the antenna, are designated as far-fields.

Microwave Field Measurement Science

For several years, NBS scientists Drs. David Kerns, Paul Wacker and Ramon Baird with Allen Newell and Ronald Bowman at the NBS Boulder labs have been working on indoor and outdoor systems for evaluating antenna performance.

The outdoor mesa range and the laboratories' indoor ranges resulted from NBS research started in the mid-1960's by which NBS scientists solved many near-field and far-field

antenna measurement problems. Considering antennas as measurable unknown quantities (black boxes),



NBS scientist John Greene points to a moveable probe that measures the microwave antenna field in an area covered by microwave absorbing cones (background).

NBS scientists developed very accurate methods for evaluating microwave antennas in the near-field. While developing a means of calculating the antenna near-field for a millimeter wavelength (short microwaves) velocity-of-light measurement, Kerns saw a way of exactly calculating antenna far-fields from antenna near-fields measured in the lab. He worked out the theory for using measurements from a receiving antenna or probe a short distance away (e.g., 1 meter) and mathematically calculating the com-
continued on page 190

How Big IS



ASKING Dr. James E. Faller why he is measuring the universal constant of gravity, (Big G) is reminiscent of someone asking George Leigh Mallory why he wanted to climb Mount Everest.

"Because it is there," was Mallory's famous reply.

Similarly, Faller sees measurement of Big G as a high-order challenge to his abilities and imagination as a physicist.

"It's the oldest track and field events of the scientific Olympics,"

he says.

Faller is a National Bureau of Standards physicist at the Joint Institute for Laboratory Astrophysics (JILA) which is operated by NBS and the University of Colorado on the CU campus in Boulder. He is also Professor Adjoint at CU and advisor to doctoral candidate William A. Koldewyn.

Koldewyn shares this enthusiasm for measuring Big G, in fact it is the subject of his thesis.

"When we get our measurement,"

says Faller, "it will be that of Koldewyn and Faller—in that order."

Major Improvement Expected

When they get their measurement, it will be a number: a number which they confidently expect to be 10—and perhaps 100—times better than the current number used as the gravitational constant. That means they will extend the present number one, or perhaps two, significant figures further to the right of the decimal place.

If they succeed, the names Koldewyn and Faller will indeed be written with the immortals of science. Measuring or improving the value of Big G is an olympian event in the world of physics. The list naming those who have measured and improved the value of Big G reads like Who's Who in the world of science, today and yesterday. It includes Isaac Newton, Pierre Bouguer, Henry Cavendish, George Airy, John Henry Poynting, C. V. Boys, Roland Von Eotvos and Paul Heyl.

Use of G

Big G is seldom used except within a scientific laboratory but the contributions of these scientists is more than academic exercise. The precise value of G is of considerable interest in planetology because it is the constant which links the densities of the planets as measured by astronomical methods with the densities of rocks as measured in terrestrial laboratories. If changes could be detected as small as one part in 10 billion (10^{10}) physicists could then determine whether the constant is changing due to such phenomena as the universe expanding.

Newton and the Apple

Gravity, as every school child knows, was discovered by Sir Isaac Newton when an apple fell from a tree and struck him on the head. This apple-inspired discovery of the earth's gravity led Newton to postulate that other bodies in the universe

have similar gravitational attraction. In fact, he concluded that all matter attracts all other matter.

Accordingly, the earth not only attracts apples, apples also attract the earth. That is not readily apparent because the earth's response to the force is made infinitesimal by its much larger mass.

Nevertheless, it has been calculated that two apples sitting adjacent to each other attract each other with a force of about .00045 dynes (16 billionths of an ounce).

Newton's Law of Gravitation

Calculation of attractive force of any two objects is possible if masses of the two objects and the distance between them is known. It is simply a matter of applying Newton's Law of Gravitation which states: Mutual action exists between each particle of matter and every other such that each particle is attracted to every other with a force varying as the product of the masses of the particles and inversely as the square of the distance between them.

An algebraic expression of the law is more concise:

$$F = G \frac{M_1 M_2}{d^2}$$

In the formula, F is the force of gravitational attraction; G is the gravitational constant (Big G); M_1 and M_2 are the masses of the two bodies attracting each other; and d is the distance between the two bodies.

It is immediately obvious that a knowledge of G is necessary to calculate the force of gravity.

Uncertain Number

Newton, who postulated G , also estimated a numerical value for it—6.6. The currently used "best number" for G is 6.672×10^{-11} in SI units. That number is pretty uncertain beyond the second decimal place and somewhat uncertain even in the second decimal place. As evidence of the uncertainty, Koldewyn cites three changes in the number (6.670, 6.6732 and 6.672) within the last 9 years. These changes, made without the benefit of new experi-

mental data, resulted from statistically reworking existing data.

The uncertainty of the number for G makes it the least precisely known of the physical constants, according to Faller. He and Koldewyn seek to change that.

Success in a London Laboratory

In 1798, English scientist Henry Cavendish (at age 67) performed the now classical measurement of G .

He mounted a 5-centimeter lead ball on each end of a 1.8-meter rod and then suspended the rod at its center with a silver-plated copper wire. On a pivot directly above the suspending wire, he rigged a heavier 1.8-meter rod and on wires hanging down from each end he hung 30.5-centimeter diameter lead spheres.

By moving the upper rod on its pivot, he moved the spheres close to the smaller balls and found that they twisted the suspending wire due to the attraction to the larger masses.

Moving the masses by means of the pivoted suspension, he repeated the experiment with the spheres near opposite balls on the other side. Again the smaller masses (balls) exerted a torsional force because of attraction to the larger masses but this time in the opposite direction. By measuring the amount of deflection of the suspended masses and the amount of torsional force required to twist the suspending wire, Cavendish was able to calculate the value of G as 6.75.

It was a number which is remarkably close to today's best value. Refinements of the Cavendish experiment have continued to yield best values for G .

One of Five

The Koldewyn-Faller project is one of five major G measurements currently going on in the world. One other is a joint venture of Allen Cook in England and Antonio Marussi in Italy. Another is being conducted by M. U. Sagitov, et. al., in

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William A. Koldewyn holds the small-mass pendulum in the position it will occupy relative to the large masses when assembled in the Big-G measuring apparatus. Dr. James E. Faller checks alignment.

Hoover at Commerce: 'Satisfying Years'

Advocate of
Standards,
Conservation,
Consumer Interests



BEFORE becoming the 31st President of the United States, Herbert Hoover—born 100 years ago (Aug. 10, 1874) at West Branch, Iowa—was the Nation's seventh Secretary of Commerce. For Hoover, the secretaryship was no mere stepping-stone to the White House. Forty years later, as elder statesman, he was to look back fondly to his years at Commerce as among the happiest and most satisfying of his life.

The National Bureau of Standards played a central role during that period (1921–28) in the odyssey of the Iowa blacksmith's son who became President. As Secretary, Hoover personally took NBS as well as the Bureau of Foreign and Domestic Commerce "under my own wing." In a series of actions which have a strikingly contemporary ring in this era of energy and environmental challenge, Hoover enlisted NBS in a crusade for the elimination of waste and the attainment of a higher quality of life.

Hoover had begun warring upon needless and wasteful varieties of manufactured goods from his previous vantage-point as president of the Federated American Engineering Societies. To aid business in recovering from an economic decline, Hoover appointed committees to explore possibilities for drafting voluntary industry standardization codes—a

move which was the inspiration for founding many of the trade associations we know today.

Once installed at Commerce, the new Secretary ordered the establishment of NBS divisions expressly devoted to Commercial Standards and Simplified Practices. By 1925 he was able to report that NBS-industry cooperation had resulted in over 50 simplifications affecting manufactured goods valued at over \$2 billion. In a talk to one of the trade associations involved, Hoover reviewed some of the progress already made against "problems of scientific character that trouble every manufacturer" and explained his concept of NBS as a great physical laboratory and common resource for trade and industry and the general public.

"Not that the Bureau of Standards should undertake the whole of these works," he emphasized, "but that it should cooperate [by allowing] industry to do the more direct research while we plunge around in the bog of science looking for things that are pretty obscure at times."

Among advances resulting from Commerce's probing into "obscure things" were methods for the better utilization of raw materials, lowering the price and improving the quality of manufactured goods and the useful exploitation of industrial by-products. Experiments in chrome tanning

of leather soles led to longer-lasting shoes. Studies in pottery glazing led to a shorter manufacturing time per unit. Demonstration of commercially practicable production of levulose—used in foodstuffs, medicine and preservatives—provided the basis for a new American industry.

Well before "consumerism" became a household word, Hoover was guiding the Department of Commerce and making regular use of its Bureau of Standards for promotion of public safety and advancement of consumer interests. He strove to make his department "more nearly meet the needs of the American business public" in fundamental ways: promoting the rational application of technology, conservation of resources, efficiency in production and distribution. All of this tied in with his earlier experiences and development as farm boy, Stanford-trained geologist, mining engineer, consultant to overseas railroad and mining firms and director of famine and war relief programs.

Stamping his master engineer and efficiency expert style upon the Department of Commerce, Secretary Hoover kept his sights fixed upon human values. "Protection of the Heads and Eyes of Industrial Workers," for example, became the subject of an early NBS handbook embodying a national safety code.

Other publications dealt with electrical safety, logging and sawmill safety, radio installation safety, protection against lightning.

"How to Get Better Service with Less Natural Gas in Domestic Gas Appliances" was treated in an NBS circular, as were hosiery sizes, rubber tips for crutches, quicklimes for use in water purification, motor vehicle headlights, divers' hose, safety matches, use and care of automobile tires.

Hoover created at Commerce an information gathering division that was particularly responsive to burgeoning business needs and he sparked standards and publications that served the entire community. Through the Bureau of Foreign and Domestic Commerce, he worked to rejuvenate American foreign trade. He created a departmental Division of Building and Housing to encourage expansion in the home-building industry as a means of postwar recovery.

He was convinced that more and better housing was a matter of top priority for several reasons. More

than a million new units were needed to remedy the existing housing shortage. But beyond this, a recovered construction industry would help to revive the economy and provide jobs for the unemployed. Extensive scientific and technical research was required, with emphasis on simplification and standardization of building materials and revision of municipal and state building codes. NBS, of course, was deeply involved.

Early in 1922, Secretary Hoover agreed to head the national advisory council of Better Homes in America. This movement that he had inspired gained increasing momentum, with volunteers working in every state. Commerce officials consulted with industry, professional and municipal leaders throughout the country while the housing division coordinated the work of NBS technical divisions and the Secretary's advisory committees on building, plumbing and zoning codes.

By the spring of 1922, home construction began a comeback. NBS published its Building and Housing Publication No. 1, *Recommended*

Minimum Requirements for Small Dwelling Construction. Next in the series came primers on plumbing, zoning, building codes and city planning. The Bureau looked into seasonal unemployment in construction and determined that much of it stemmed more from custom than from climate, a finding which began to have some beneficial effect on prevailing practices. New home building in 1922 totalled more than 700,000—about twice the previous year's volume.

While housing was a major interest, Hoover was quick to recognize and champion fledgling industries with potential for an important impact on future commerce. Airborne transportation and communication captured his imagination early, and in 1926 and 1927 Aeronautics and Radio Bureaus were added to the Department of Commerce by acts of Congress.

Hoover put radio to dramatic use when America's largest peacetime disaster up to that time struck in the spring and summer of 1927. Secretary Hoover, appointed by President Coolidge to rescue 1,500,000 people from the path of Mississippi floods, mobilized public officials and the militias of six endangered states, the Coast Guard, the Red Cross, Naval airmen and Army engineers. From Memphis and other disaster sites he directed rescue, relief and reconstruction operations, and took to the airwaves to help the Red Cross raise \$15 million in financial support for the gigantic struggle to alleviate that catastrophe.

Today's NBS disaster teams operate out of the Bureau's Center for Building Technology in times of flood, earthquake, hurricane, explosion or fire. They carry on in the Hoover tradition of science and engineering applied to human need—one of many current illustrations of Herbert Hoover's continued influence on the Department of Commerce and the National Bureau of Standards 100 years after his birth. □



Herbert Hoover (center), conservationist, led group on pilgrimage highlighted by this collective "embrace" of a giant tree in Sequoia National Park. (Photo courtesy U.S. Information Agency.)

Mechanical Failure

A Material Matter

Excerpts of a speech given by NBS Director Richard W. Roberts before the recent Mechanical Failures Prevention Group Symposium.

WITH the production of millions of products and structures, I don't find it surprising that some are subject to mechanical failure. Almost no system is foolproof. Rather, I find it surprising that so many things work so well for so long. This is certainly a credit to American technology. But mechanical failures do occur, and our goal should be minimization of their frequency and consequences.

The break-up of Liberty Ships during World War II, the failure of Comet Aircraft in the 1950's and the recent rash of gas pipeline ruptures remind us that we live in a mechanically imperfect world. And, as we build larger structures, the potential for disaster is magnified.

Consequences of Failure

There are, of course, varied consequences of mechanical failure. Death or disability can be one tragic outcome, causing anguish to the victims or their survivors and often leading to lawsuits for the recovery of damages.

Economic loss is also associated with mechanical failure, and sometimes this can be a double-action effect. For example, when a machine on the assembly line breaks down, there is not only the cost associated with repairing or replacing it, but also the cost of lost productivity.

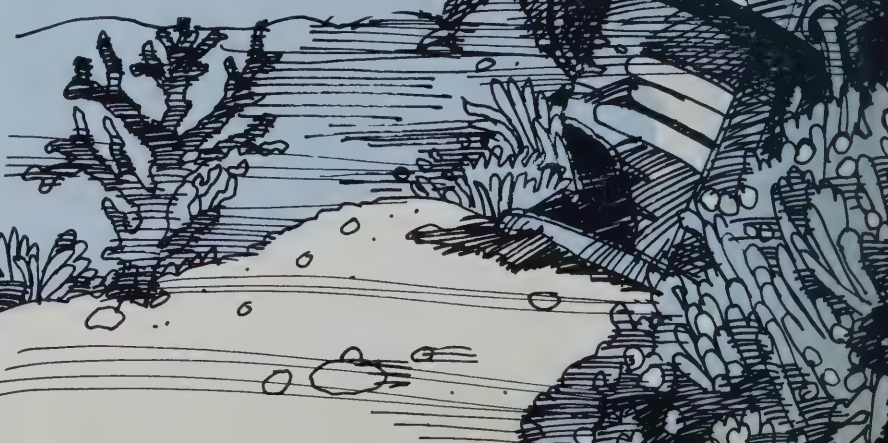
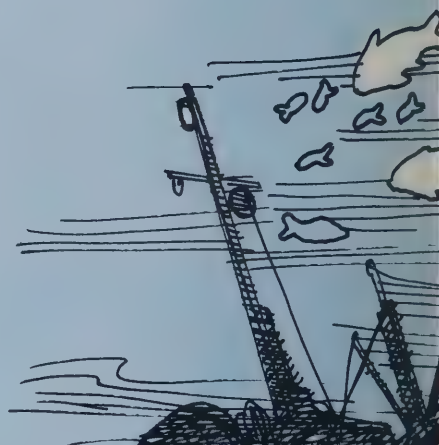
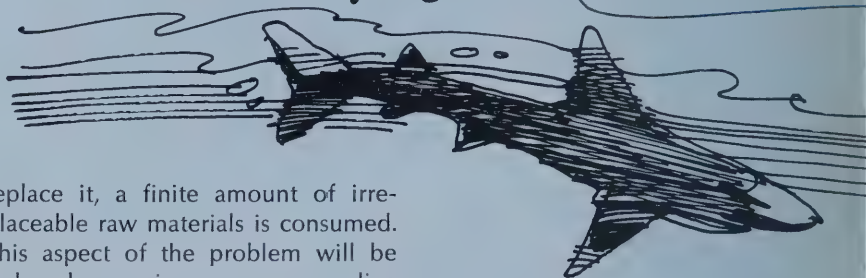
Another consequence of mechanical failure is that of materials waste. When an item breaks down and we

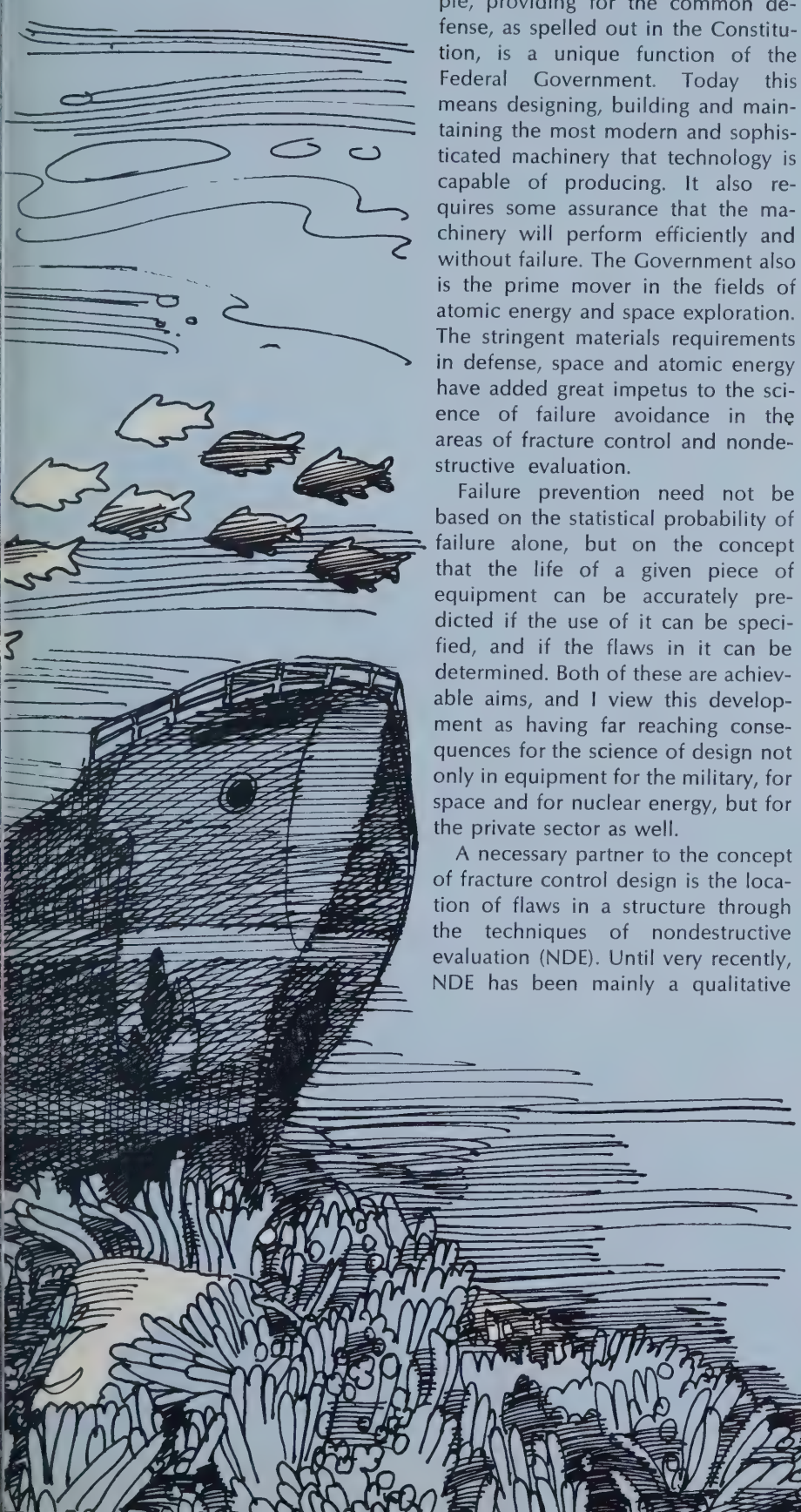
replace it, a finite amount of irreplaceable raw materials is consumed. This aspect of the problem will be reduced as we improve our recycling ability, but we've got a long way to go in this area.

A final consequence of mechanical failure is that of frustration. Almost everybody has experienced the flash of anger when the family chariot burns out a bearing on the Interstate, or the local repair shop tells you the central air conditioner will be out of action all summer because compressors are back-ordered at least 3 months. Not only is this frustrating, but it also leads to disillusionment with the system. When things break down, when repairs are slow, difficult, costly or impossible, some people turn off from technology. And I can't always blame them.

Government Concern

I think we all agree that failures do occur, with consequences ranging from major disaster to minor inconvenience. Why is the Federal Government concerned? There are a number of reasons. First, the Government has certain missions that, because of





their nature or sheer size, are clearly its special responsibility. For example, providing for the common defense, as spelled out in the Constitution, is a unique function of the Federal Government. Today this means designing, building and maintaining the most modern and sophisticated machinery that technology is capable of producing. It also requires some assurance that the machinery will perform efficiently and without failure. The Government also is the prime mover in the fields of atomic energy and space exploration. The stringent materials requirements in defense, space and atomic energy have added great impetus to the science of failure avoidance in the areas of fracture control and nondestructive evaluation.

Failure prevention need not be based on the statistical probability of failure alone, but on the concept that the life of a given piece of equipment can be accurately predicted if the use of it can be specified, and if the flaws in it can be determined. Both of these are achievable aims, and I view this development as having far reaching consequences for the science of design not only in equipment for the military, for space and for nuclear energy, but for the private sector as well.

A necessary partner to the concept of fracture control design is the location of flaws in a structure through the techniques of nondestructive evaluation (NDE). Until very recently, NDE has been mainly a qualitative

tool, very useful for the detection of major flaws in materials. However, with the advent of a drive toward fracture safe design, NDE is moving to a higher level of precision. The reason is simply that fracture control design places quantitative requirements on the detection of flaws, and these new requirements are causing rapid developments in the quantification of NDE.

Despite the advances that have been made, NDE is not yet a precision technique. A great deal of fundamental work lies ahead if NDE is to become a truly useful, quantitative tool.

Health and Welfare

The Government is also concerned with the health and welfare of the people. Congress has created special agencies whose primary concern is public safety, and mechanical failure prevention is a major concern of these agencies. One of the newest is the Consumer Product Safety Commission, created in response to a new wave of consumerism that has grown over the past 10 years. Some other agencies involved with public safety are: the Federal Highway Administration, responsible for the correction of highway conditions that contribute to accidents; the Coast Guard, involved with merchant marine safety; and the Federal Aviation Administration, charged with rules, regulations and minimum standards relating to the manufacture, operation and maintenance of aircraft.

This concern for public safety is such that, when the private sector cannot do the job alone, it is appropriate for the Federal Government to join in.

The Government is also concerned with the economic health of the Nation and has legitimate interest in mechanical failures that may cause undue economic dislocation. And, finally, the Government is the world's largest consumer and, like us as indi-

turn page

MECHANICAL *continued*

viduals, wants its purchases to be safe, economical and long lasting. In 1972, Uncle Sam purchased over \$1.6 billion worth of supplies and equipment for civilian agencies and \$58 billion for the military. Through this huge purchasing activity the Government can do much to influence the reduction of mechanical failures, an area under investigation by the NBS Experimental Technology Incentives Program.

Public Policy

In all of its concerns, be they military, health and welfare or space, Government policy is concerned with mechanical failures.

The President, of course, helps formulate public policy. President Nixon has done so in his Buyer's Bill of Rights, in which he states that the consumer has a right to safety in the products he buys. This credo obviously has implications for mechanical failure prevention, as there is often a direct tie between failure and injury.

Congress formulates policy through legislative enactments, and many acts of Congress have impact on mechanical failure. For example, the Natural Gas Pipeline Safety Act is directly concerned with protecting the public from this class of mechanical failure.

Neither the President nor the Congress can carry out policy on a day-to-day basis, so a number of Federal agencies have been established to do so. These agencies, in interpreting and executing national policy, often establish rules, requirements and procedures that are in effect mini-policies of their own. In addition, the standard-setting efforts of the private sector have policy impact, for such standards are often used in the requirements of various Government agencies.

Now none of this policy setting is done in a vacuum, nor is it a one-way street. The President and Congress reflect the will of the people and respond to the needs of the day.

Product Liability

The courts, too, play a major role in policy setting. They not only interpret formal legislation, but they also provide a forum for the challenge of specific rules set by Federal agencies. And the courts play a major role in their interpretations of common law—by common law I mean that arising out of precedents and not out of



Shown here is wreckage of a furniture warehouse destroyed by a gas explosion. The accident was attributed to a cracked gas pipeline, possibly caused by the activities of heavy construction equipment operating in the area.

legislation—and here, too, they are having broad impact.

Not only is the absolute number of product liability suits growing astronomically, but there has been a drastic change in court climate regarding liability. A hundred years ago courts held that the manufacturer had no liability except where a contractual relationship existed. Over the years there was a shift to the sit-

uation in which the plaintiff had to prove negligence on the part of the manufacturer to the situation today in which the plaintiff need only prove that the article was unsafe in some way which caused him injury or damage to win his case.

At a time when sophisticated new engineering applications and shortages of traditional materials put a premium on innovations in materials and on imagination in design concepts, this legal climate may lead to an overly cautious approach by industry—causing, for example, the avoidance of new materials, overdesign and delays in marketing. This is an appropriate area for new policy—for strong governmental support of materials characterization research and development of NDE test methods. Advances in these technical areas would benefit the public and the manufacturer and would lessen the load on the courts.

Policy Needs

Policy is a many-faceted thing. It embodies what we as a nation hope to achieve as well as the courses of action by which we get the job done.

The Government should foster the development and use of reliable NDE techniques so that safe, long-lasting products can be made available at reasonable cost. There will be other benefits. With longer lasting products, there will be reduced needs for raw materials, less energy used in the production and transportation of goods and less pollution at both the production and disposal ends of the cycle.

We need both policy and technology that leads to increased recycling and reuse. We need a better understanding of the relationship between flaws and failure. We need research into the characterization of materials, so that they can be better matched to service requirements. And, finally, there should be a *clear* definition of liability when the rare unavoidable failures do occur. □

HIGHLIGHTS

Boulder Open House

The Commerce Department's laboratories in Boulder, Colo.—NBS, the National Oceanic and Atmospheric Administration and the Office of Telecommunications—will hold an open house on September 12–14, 1974. In the first such event in 10 years, approximately 25 laboratories will be open for inspection. Several special exhibits will be featured—including "A Walk Through Time."

September 12–13 will be devoted primarily to prearranged group tours. On September 14, the laboratories will be open to the general public. Information and maps will be provided; guides will also be available.

For additional information, write to the Program Information Office 270.00, NBS, Boulder, Colo. 80302.

New Sleepwear Standard

The Bureau recently provided the technical base for a flammability standard for children's sleepwear sizes 0 through 14. This standard, which was published by the Consumer Product Safety Commission (CPSC) in the May 1, 1974, *Federal Register*, will become effective on May 1, 1975.

The new standard is a modification of the flammability standard for children's sleepwear sizes 0–6X, which became law on July 29, 1972. When the new standard takes effect, fire retardant sleepwear will be required for all children's sizes 0 through 14, providing protection for most children of ages 0 through 12.

Catalog of NBS Papers Available

All NBS papers published in NBS and non-NBS media during 1973 are cited in "Publications of the National Bureau of Standards—1973 Catalog." The citations for all NBS papers in-

clude full title, author(s), place of publication, abstract and key words. Permuted author and key word indexes are also included. Information on previously published NBS catalogs and an availability status table on papers are given.

Order from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402, as SD Catalog No. C13.10:305 Supplement 5.

Largest Molecule Yet Detected in Space

The most complex molecule to be detected in interstellar matter has been observed by NBS scientists (one a visiting fellow from the University of Virginia) and staff from the National Radio Astronomy Observatory (NRAO), from the U.S. Naval Research Laboratory (NRL) and from the Goddard Space Flight Center. The molecule—dimethyl ether, $(\text{CH}_3)_2\text{O}$ —was detected through its mm-wave emission at 90.9 and 86.2 GHz in the direction of the Orion Nebula molecular cloud. The studies were done at NRL's Maryland Point Observatory and at the NRAO telescope at Kitt Peak near Tucson, Ariz.

The observed spectrum, although complicated, lends itself to analysis and gives hints about the environment in which the molecules are found.

Index of International Standards

The Bureau recently compiled an index of international standards, recommendations, test methods, analyses and specifications. Based on the Key-Word-In-Context system, the index contains over 2,700 standards titles of the International Organization for Standardization, the International Electrotechnical Commission,

the International Commission on Rules for the Approval of Electrical Equipment, the International Special Committee on Radio Interference and the International Organization of Legal Metrology.

The Index of International Standards may be ordered as SD Catalog No. C13.10:390 from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402, for \$5.60.

Crude Oil Density Study

NBS has recently signed a 5-year contract to provide the American Petroleum Institute with an extended set of reference data on the density of crude oil and petroleum products. Reaffirmation of density data is needed to ensure accurate transfer of oil products, particularly in international markets.

The effort will require gathering samples of petroleum crude from oil fields around the world according to carefully developed sampling procedures. From density measurements made by NBS on these samples, a set of reference tables will be established for the commercially acceptable densities of crude oil.

Machine Tool Show

NBS scientists, engineers and technicians will participate in a working exhibit at the 1974 International Machine Tool Show to be held September 4–13, 1974, in Chicago's International Amphitheatre and McCormick Place. The exhibit is part of NBS' Operation Outreach, which aims at learning first-hand some of the measurement problems associated with the metal working machinery and equipment industry.

The exhibit will present an overview of NBS with particular emphasis on the fields of dimensional technology, optics and micrometrology. The NBS representatives will discuss measurement problems, such as dimensional measurements and surface finish measurements, with conference participants. □

NBS Automates Bolometer Calibrations

MICROWAVE technology is a multi-billion dollar national investment whose diverse dividends include ship and aircraft navigation systems, communications networks and meals cooked rapidly in microwave ovens.

To help strengthen the foundation of this vast technology, the National Bureau of Standards, Boulder, Colo., is announcing an automated microwave power measurement capability that is cheaper and more thorough than the manual methods being replaced.

This new NBS capability is an integral part of the national measurement system and is an attempt to promote economy and uniformity in domestic commerce. For example, the expense of a microwave system increases with the uncertainty in the engineer's power measurements. That is, he must overdesign the system to compensate for his inability to measure power accurately. Uniformity is a consequence of accuracy and assures, for example, that 5 milliwatts (mW) of microwave power measured in Seattle will be 5 mW on a meter in Boston.

The NBS system, employing a commercial automatic network analyzer (ANA), can calibrate a bolometer unit at any frequency from 2 to

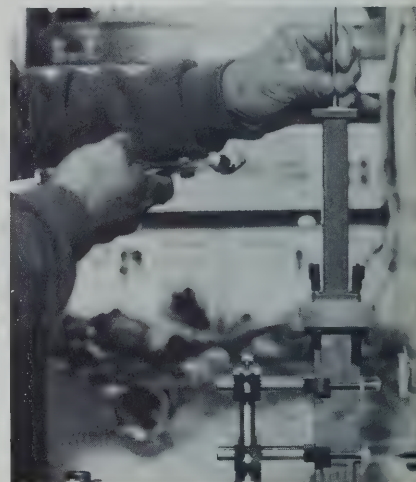
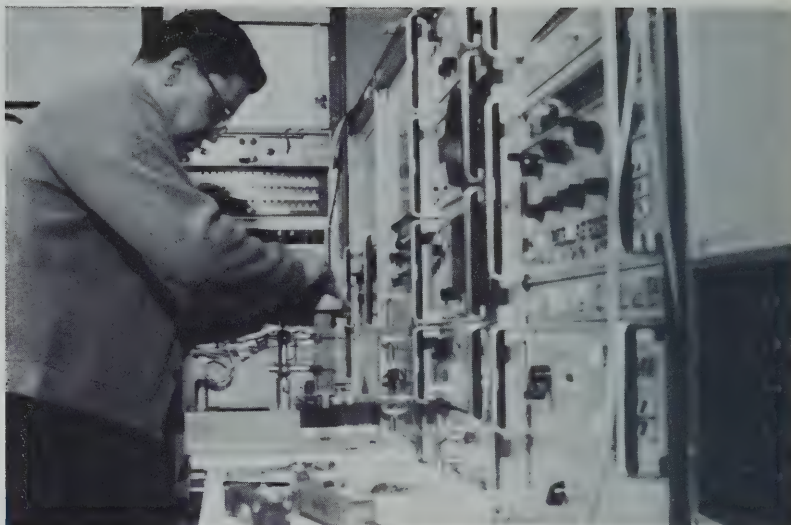
12.4 gigahertz (GHz, one billion cycles per second). A calibration covering 20 frequencies in one of the bands 2-4, 4-8 and 8-12.4 GHz costs about \$700, while the manual calibration at three fixed frequencies costs about \$1200. Thus the cost per frequency point has been reduced from \$400 to \$35.

The automated system calibrates bolometer units (waveguide and coaxial connector types) in the power level range from 1 to 10 mW.

Using a microcalorimeter as its primary standard for microwave power measurements, NBS calibrates a precision working-standard bolometer unit as a function of frequency. Then, at each desired frequency, the effective efficiency of the bolometer unit being calibrated is obtained in terms of the effective efficiency of a working-standard bolometer unit. At present this data is

Technician Fred Jeffers prepares to calibrate the NBS automated measurement system prior to a bolometer unit calibration.

This microwave sliding short circuit helps calibrate the NBS automated measurement system employed in bolometer unit calibrations.



certified only at the fixed frequencies of the manual calibration systems, though NBS hopes to be able to specify the accuracy of the automated bolometer unit calibration system at all intermediate frequencies soon.

A further improvement planned for this NBS service is the separation of estimated systematic errors from random errors for each calibration point. The uncertainties in the measured effective efficiency are expected to be comparable to those of the manual calibration systems.

Persons wishing more information on this NBS measurement capability may contact E. L. Komarek, Electromagnetics Division, National Bureau of Standards, Boulder, Colo. 80302. □

Magnetic Eye Spots Weak Tanks

CARRIER landings are rough on aircraft and their cargos. When the latter comprise double-walled stainless steel tanks containing liquid oxygen, such jostling can dangerously weaken the tanks at their points of support. The National Bureau of Standards in Boulder, Colo., has developed a small magnetometer that pinpoints this impending failure by monitoring the local magnetic state of the tank wall.

Frederick R. Fickett of the NBS Cryogenics Division designed and built the magnetometer, a device for detecting and measuring magnetic fields. The magnetometer head is a disk 2.8 cm in diameter and 1.5 cm high. When placed against a stainless steel tank the head transfers signals to a voltmeter whose readings reveal the magnetic condition of the tank wall.

Normally 304 stainless steel is nonmagnetic, but plastic strain at low temperatures produces a component called martensite, which can retain a magnetic field. By sensing martensite and measuring its percentage in the steel, the magnetometer acts as a fatigue monitor. At the temperature of liquid oxygen (90 K), martensite itself does not weaken the steel but its presence indicates that the structure has been stressed.

There are many commercial magnetometers available, as well as custom devices described in technical journals. Fickett surveyed these and found none meeting all requirements of the Naval Air Engineering Center, the sponsor of the NBS project. The magnetometer then designed by Fickett will:

- Detect a minimum of 3 percent martensite and measure this concentration with an uncertainty of ± 1 percent.
- Operate from room temperature to 90 K and remain unaffected by cycling over this range.
- Withstand mechanical shocks equivalent to those of a carrier landing.
- Be small enough to fasten easily and permanently to the outside of the inner tank wall.
- Have all electrical leads terminated at a fixed socket to allow remote operation and in-place calibration.
- Be simple to operate.

After considering several means of detecting and measuring a magnetic field, Fickett chose the Hall effect. When a current-carrying wire is per-

pendicular to a magnetic field, the flowing electrons are deflected by the field and give a negative charge to one side of the wire. The opposite side, therefore, acquires a net positive charge. The resulting Hall voltage across the wire is proportional to the magnetic field and can be calibrated to give field values from voltage measurements.

Of course, the NBS magnetometer can do its sleuthing only if the martensite possesses a tell-tale magnetic field. Therefore, an electromagnet in the magnetometer generates a field that passes into the wall of the steel tank being examined. Any martensite will remain magnetized after the field is removed. The residual field, when detected by the Hall probe, reveals the amount of martensite in the tank wall.

Many other possible applications exist for the device. Basically it provides a rapid means for detecting low temperature stresses in any stainless steel structure. Such structures are quite common, varying from large river barges carrying liquid hydrogen to relatively small pipelines in liquefaction plants. □

More Versatile Heat-Pipe Ovens Developed

TWO new versions of the heat-pipe oven—concentric and crossed heat-pipe ovens—have been developed at the National Bureau of Standards that extend its usefulness to studies of diatomic molecules. These ovens generate vapors of metals that combine with rare gases and other metal vapors to form new molecular species.

NBS scientists combined two conventional heat-pipe ovens in different ways to form the new con-

centric and crossed heat-pipe ovens. By crossing two ovens at right angles, Merrill M. Hessel produced the crossed heat-pipe oven, which allows a laser beam or other light to enter along one arm and excite the vapors inside the oven. The light emitted by the fluorescing vapor can be studied through another arm. By adjusting the power applied and the pressures in the ovens, scientists can position various regions of the vapor-gas mixture. *turn page*

HEAT-PIPE *continued*

ture in front of the cross-arm to make detailed analyses of different gas ratios and molecules.

Building one oven inside another, C. Rudolf Vidal, Frank Haller and Hessel created the concentric heat-pipe oven in which the outer oven defines the temperature of the inner one. Using this arrangement, they found that two different vapors of substantially different vapor pressures could be generated in the inner oven. When the temperature and pressure inside the ovens are adjusted, any desired ratio of vapors or molecules of two metals can be produced.

In cooperative projects with the Lawrence Livermore Laboratory and the Los Alamos Scientific Laboratory (LASL), Hessel, Earl W. Smith, Robert E. Drullinger and Haller of NBS, Quantum Electronics Division are currently using the new heat-pipe ovens to study possible candidates for metal-vapor lasers. These projects are primarily aimed at defining the characteristics of metals used in metal-vapor lasers, which may be used to initiate the thermonuclear fusion process.

Under the NBS-Lawrence Livermore Laboratory program, a concen-

tric heat-pipe that operates at 800 °C and 10 atmospheres pressure will be built. Using this oven, researchers will analyze the behavior of such alkali metals as lithium, cesium or mercury and cadmium mixed with such inert gases as argon, xenon and helium. Energy to initiate laser action will be provided by a super high-powered (1 MeV and 100 kA) electron beam entering the side of the pipe. These electrons, in a beam 2-cm thick and 50-cm wide, excite the metal-rare-gas molecules. As the molecules fall back to the ground state, they may emit coherent energy in the form of a powerful laser beam. Many different metals and rare gas combinations will be examined with this device.

The LASL contract calls for NBS to study mercury, and perhaps cadmium and zinc vapors in the future, as potential high-powered laser material. Some of these studies, aimed at developing spectroscopic measurement techniques for this class of molecules, are being done in a high-pressure crossed heat-pipe oven. □

For further information on heat-pipe ovens, see "New Oven Constrains Corrosive Vapors," Technical News Bulletin March 1973, p. 58, and "Heat-Pipe Oven Generates Homogeneous Metal Vapors" Technical News Bulletin, August 1969, p. 172.

Building one oven inside another, NBS scientists created the concentric heat-pipe oven which will be used to analyze the behavior of alkali metals.

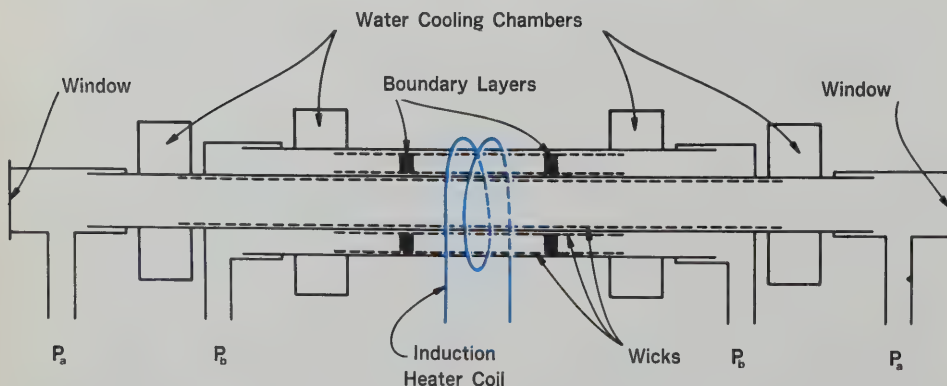
Magnetometer May Help Predict Earthquakes

LONG-term variations in the earth's magnetic field can now be measured with a new type of magnetometer developed cooperatively by the National Bureau of Standards, the National Oceanic and Atmospheric Administration, the U.S. Geological Survey and the University of Colorado.

If a reliable correlation between the earth's magnetic phenomena and seismic events can be found, the data obtained using this magnetometer may help predict the occurrence of earthquakes. Changes in the local magnetic field in fault zones may be one of half a dozen types of phenomena which will be monitored for earthquake prediction in the future.

The magnetometer combines the best characteristics (speed and sensitivity) of the widely used self-oscillating rubidium magnetometer with a calibration system for removing instrumental errors and drifts. The resulting device can measure variations of less than one-millionth of the earth's magnetic field over periods of weeks, months or years.

This new tool may help locate stress accumulations in the earth's crust through continued measurements of the earth's magnetic field.



Pairs of magnetometers could be set up in seismically active areas, with one magnetometer near a known fault location and the other about 10 kilometers away. Any change in stress along the fault would change the magnetic properties of the nearby rock, and this would show up as a change in the measured field for one magnetometer but not the other. Changes in field due to variations in electrical currents in the earth's upper atmosphere would be seen nearly equally on both magnetometers, and thus could be separated from the effects of changes in stress along the fault.

The first prototype self-calibrating rubidium magnetometers were constructed and tested about 3 years ago by Peter L. Bender of the National Bureau of Standards and J. H. Allen of the National Oceanic and Atmospheric Administration. Since then Russell Brill of the University of Colorado Department of Physics and Astrophysics, with financial support from NBS and technical assistance from the U.S. Geological Survey, has built and operated field-usable versions of the magnetometers. Measurements have been made with the new magnetometers at two sites 12 km apart near Boulder, Colo., in order to see how nearly uniform the earth's natural magnetic field changes are.

Results obtained with the magnetometers indicate that most of the natural field variations observed are the same at the two Colorado sites. A substantial part of the small observed differences are due to the local variations in the conductivity of the ground, and methods of correcting for this effect are being developed. It thus appears that very small and gradual stress-induced changes in the magnetic properties of the crustal rock near one magnetometer could be detected successfully.

Rubidium magnetometers operate on the principle that the precession frequency (Larmor frequency) of the rubidium atom will be closely pro-

portional to the magnetic field. A given field strength will always produce the same precession frequency. The process is analogous to the motion of a child's top under the influence of gravity. If the force of gravity were to increase the top would precess faster.

One section of the two-part mag-

netometer is very good at tracking rapid changes in the field strength, while the other is very accurate and stable in measuring the actual value of the field, but is not as fast to track a change. When connected, they complement each other and provide a rapid, sensitive, accurate, self-calibrating instrument. □

Guide to Courtroom Systems Prepared

"Justice delayed, is justice denied"
—William Ewart Gladstone

RECENTLY National Bureau of Standards scientists Don R. Boyle and Alan R. Cook of the Electromagnetics Division prepared a "Guide to Courtroom Audio Tape Recording" for the NBS Law Enforcement Standards Laboratory. The work was sponsored by the Department of Justice, Law Enforcement Assistance Administration, National Institute of Law Enforcement and Criminal Justice and will be published by them. The guide provides court administrators with a single source containing guidance in the production of successful electronic recording and verbatim records.

With huge transcription backlogs, acute and growing shortages of qual-

ified court reporters and more courts requiring records, court administrators are considering electronic magnetic tape recording for obtaining court proceedings. Looking at the benefits and problems of various systems currently being used, Boyle and Cook prepared the guide to aid court administrators in selecting facilities, equipment and procedures.

Court administrators in the Alaskan State system, using magnetic tape recording since 1960, like its performance, even though it could be improved. Tapes quickly resolve questions on what transpired, for reviews and for appeals (about 5 percent of the cases). Appeals for the advantage of delay were greatly reduced. An observed disadvantage—long and sometimes critical portions turn page



NBS has prepared a user guide to help court administrators set-up and operate successful magnetic tape systems in the courtroom.

of the proceedings were undiscernible or inaudible due to inadequate sound pickup or extraneous sound masking pickup. Stringent control over courtroom demeanor was required to insure good recording.

The guide is aimed at the non-scientist and includes a glossary of technical jargon. With the guide, the reader can evaluate costs, prepare the courtroom for recording, choose effective tape recording systems and techniques and plan maintenance and training programs. The guide also provides information on how to monitor events and performance, establish courtroom procedures for optimum recording, transcribe and store tapes and recognize system capabilities and pitfalls.

Specific recommendations are made on how to handle such problems as unintelligibles due to language difficulties, nonverbal acts, indistinct or inaudible sounds and malfunctioning recording equipment.

The user guide recommends that each part of the system be considered for its effect upon the whole. Air conditioning and acoustics should receive attention because indoor and outdoor noise, sound reverberation or room deadness lower recording quality and increase transcribing time and cost. Microphone type, pickup pattern and output mixing must be carefully considered for optimum courtroom recording quality. For verbatim courtroom recording, events should be recorded directly through strategically placed open microphones. Event logging methods given in the user guide were chosen for effective documentation of playbacks and transcriptions. Procedures are also given for cases of equipment failure or inadequate recording.

After a critical review by NBS and the sponsor, the guide will be printed by the Government Printing Office. It should be available late in the year. □

Color TV Used to Calibrate Oscillators

RESearchers at the Boulder laboratories of the National Bureau of Standards have developed a series of techniques which use network television signals to calibrate oscillators with accuracies approaching a part in 10^{11} , in 15 minutes or less of measurement time.

This combination of speed and accuracy exceeds that of any other system of frequency calibration available today and accomplishes it at relatively low cost. For example, short wave radio broadcasts can achieve only 1×10^{-7} accuracy (a part in 10^7) if propagation conditions are favorable, and low frequency broadcasts can provide 1×10^{-10} only after one day of averaging or 1×10^{-11} in a week of averaging. Such long averaging times for high accuracy are obviously inconvenient and, when the oscillator under test has a drift rate exceeding a part in 10^{10} per day, they become useless.

The new techniques permit anyone with a color TV set to "borrow"

the networks' atomic frequency standards for his test. All four major networks (ABC, CBS, NBC and PBS) use rubidium-controlled oscillators to create the 3.58-MHz frequency that forms the color burst signal. This stable signal is present in all network-originated color programs, and when a TV set is tuned to a live network program (not delayed on tape by the local station), the TV set's circuit is locked to this frequency.

NBS measures the networks' frequencies regularly and publishes their relationship to the NBS standard frequency.¹ Thus, a user can calibrate his own oscillator in terms of the NBS standard by using TV.

There are several ways to extract this frequency from the TV receiver and use it to calibrate another oscillator. In order of increasing complexity, four techniques developed at NBS are: the "RF Color Bar Comparator," "Video Color Bar Comparator," "Digital Subcarrier Comparator" and "Digital Offset Computer."

The "RF Color Bar" technique requires no modification to the TV set and achieves 1×10^{-9} accuracy in less than 5 minutes of measurement. For a parts cost of less than \$50, a small electronic circuit can be built which creates a vertical rainbow colored bar on the TV screen when attached to the antenna terminals. When the oscillator under test is plugged into the circuit, the bar moves across the screen at a rate proportional to the difference between the tested frequency and the network frequency. When the difference is small, the motion is very slow, and the bar changes colors at a rate proportional to the difference.

The digital offset computer displays the current 10 samples of frequency difference in the left column and the averages of 10 groups of 10 samples each in the right.



The test oscillator must have a frequency of $5/N$ MHz when $N = 1, 2, 3, \dots$. By timing the number of seconds required for the colors to change from red through blue, green and back to red, the difference between frequencies can be calculated.

The "Video Color Bar" technique is very similar, except that the color calibration signal is injected into the chroma circuit instead of the antenna terminal. This requires the addition of a resistor and two capacitors to the TV circuit, but does not interfere at all with normal program reception. The advantage is an improvement in the appearance of the color bar, which improves the resolution of the measurement. This version permits 1×10^{-10} accuracy in 5 minutes.

The third version requires more elaborate circuitry and provides greater accuracy. Called the "Digital Subcarrier Comparator," it generates a narrow vertical line that proceeds slowly across the screen and then snaps back rapidly, acting as an analog indicator of the phase difference between the frequency being tested (or adjusted) and the reference signal from the network. At the same time, the period of one cycle of this phase difference is indicated by a 4-digit counter. Accuracy to one part in 10^{10} is possible in $1\frac{1}{2}$ minutes of measurement time, or 2 parts in 10^{11} in about 15 minutes.

The most accurate and easiest-to-run is the fourth technique which is almost completely automatic. The circuits developed by NBS take a series of averaged readings, automatically compute the difference between test oscillator and reference signal and display the difference in 10 four-digit numbers on the TV screen. The numbers are averaged by the operator to obtain an accuracy approaching one part in 10^{11} in 15 minutes. □

NBS Time Services Bulletin, published monthly. Subscriptions may be obtained by writing to NBS Time and Frequency Services Bulletin, Frequency-Time Broadcast Services Section, Time and Frequency Division, National Bureau of Standards, Boulder, Colo. 80302.

Frequency Standard Systems Compare Atomic Time Scales

THE National Bureau of Standards laboratories in Boulder, Colo., currently maintain two of the world's most accurate primary frequency and time standards. Designated NBS-4 and NBS-5, these devices form a system capable of mutually supporting each other or operating independently. Each device is recognized as a primary standard for frequency and the unit of time.

NBS-4, became operational in August 1973; NBS-5 was first operational in January 1973. NBS-4 has been used on a continuous basis for six calibrations of the NBS atomic time scale and is currently available on a monthly or bi-monthly basis for this purpose. Modifications are being made on NBS-5 to improve stability and to make possible an operational capability on a continuous service basis.

Measurement Evaluations

During recent evaluations the stabilities of NBS-4 and NBS-5 were checked against each other and against other high performance crystal and cesium oscillators. NBS-4 can be characterized by a frequency stability of $1.5 \times 10^{-12} t^{-\frac{1}{2}}$ and NBS-5 can be described by $9 \times 10^{-13} t^{-\frac{1}{2}}$, where t is in seconds. In a comparison between these two primary standards a flicker "floor" (best stability) of 9×10^{-15} was reached.

Accuracy evaluations of both devices were conducted separately and independently. Sources of uncertainty included measurement of the magnetic field, magnetic field inhomogeneities, microwave excitation spectrum, servo system shifts and others. The most significant accuracy limita-

tion, the cavity phase shift, was checked and measured using three different methods. NBS-5 was subjected to three methods:

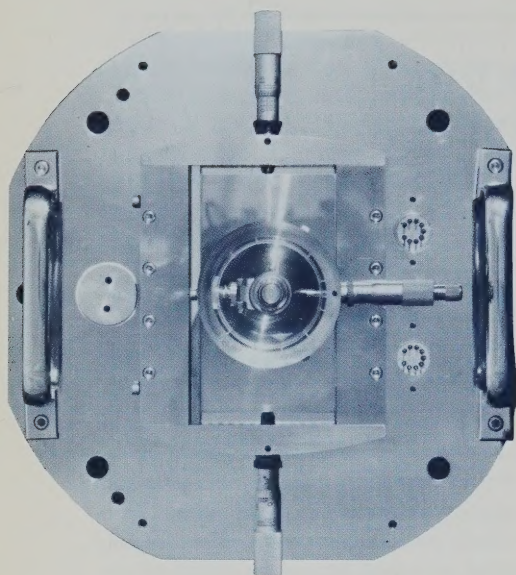
- Reversal of the beam direction.
- A frequency shift experiment using different atomic velocities, which were selected by pulsed operation of the microwave excitation.
- Measurement of the velocity distribution followed by a frequency shift experiment where the power of the microwave excitation was changed in a controlled way.

NBS-4 was checked only by the third method.

The second order Doppler effect correction was obtained for both devices from the velocity distribution of the atomic beam, which was determined from pulsed excitation and analysis of the microwave spectrum. All of the different mentioned methods led to a satisfying agreement within the independently assigned uncertainties. Individual and independent full accuracy evaluations of one sigma uncertainties of 2×10^{-13} (NBS-5) and 3×10^{-13} (NBS-4) were achieved. By the use of a series of the evaluations (the memory of each resting with the continuous NBS atomic time scale) an accuracy of close to 1×10^{-13} was achieved. At present, the reproducibility of either NBS-4 or NBS-5 is estimated at better than 1×10^{-13} .

Measurements of TAI

Since January 1973, NBS-4 and NBS-5 have together provided 13 individual calibrations of the NBS atomic time scale. The relationship
turn page



One of two identical endplates on NBS-5.

FREQUENCY *continued*

between the International Atomic Time Scale (TAI) maintained at the Bureau International de l'Heure in France and the NBS atomic time scale is compared and determined via use of the Loran C navigation signals and the occasional use of portable cesium clocks. Between January and September 1973, a change in TAI of approximately -3×10^{-13} was noted. Since September 1973 the TAI rate has not changed. A value of 10×10^{-13} has been assigned for TAI by NBS as compared to NBS-4 and NBS-5 for this period of time. This value includes a correction of 1.8×10^{-13} for the Boulder, Colo., altitude. The one sigma uncertainty is 1.6×10^{-13} which includes the Loran C measurement uncertainty. This result means the second, as delivered internationally to the user, is too short by 10 parts in 10^{-13} . A similar result was independently obtained by the Physikalische Bundesanstalt, Germany, and by the National Research Council of Canada using their respective primary standards. □

MICROWAVES *continued*

plete antenna field at any distance. Practical implementation of this theory has led to the NBS near-field scanning technique for determining antenna properties.

Expansion of the NBS work has led to a partial replacement of the conventional far-field method. This earlier method requires signals transmitted from distant towers or satellites. Occasionally, airplanes are flown through the far-field to measure antenna radiation. Aside from being expensive, such measurements give only a fragmentary picture of the whole microwave field. In addition, the far-field measurements of electrically large microwave antennas (greater than 50 to 100 wavelengths in diameter) require great distances and heights above the ground to avoid large errors from ground reflections.

In another approach to lessen the need for large ranges, Wacker, a collaborator of Kerns, worked out an extrapolation technique for accurately, economically and conveniently measuring microwave antennas using much smaller ranges than in the far-field method. The mesa range for the extrapolation technique has a pair of 6-meter-high antenna towers on platforms, which move on a 60-meter-long, precision-laid track. Smaller ranges in the laboratory are used whenever they provide greater convenience, accuracy or information than the outdoor mesa range.

Like measuring the focusing power of a lens, scientists using the extrapolation range determine in one or more directions the antenna gain, a measure of the power concentration of the microwave beam. Although gain is related to size, microwave antennas can be small and still have high gain.

The extrapolation method takes into account measurement problems arising from close proximity of the antennas and multiple reflections between them. Also, overlapping data

agree among the new and old methods, adding to NBS scientists' confidence in their methods.

Measurement Applications

The short distances employed in the scanning method are ideal for evaluating millimeter-wave antennas, where the waves are highly absorbed in the atmosphere. Whereas, in the far-field, some millimeter waves either won't have enough energy left to measure or won't tell scientists how an antenna is going to perform in space where the atmosphere effects are absent.

For scanning measurements, NBS scientists have built an automated computer-controlled near-field scanner that can scan a 4.5-meter-square area. It requires a two-story room, and can handle most microwave antennas. The scanning technique can evaluate a small nosecone radar antenna in an aircraft or one aboard a large ship (where the scanner may be brought to the antenna site), a satellite TV antenna for continental coverage, or an earth resource sensing antenna. This amount of antenna information has never before been obtained by any other method. The NBS scanning system is also used as a model for making similar installations in government and industry around the country.

For safety and defense, scientists can use this scanning technique to evaluate a phased array antenna, a group of fixed antennas working together, which may follow many missiles or airplanes at the same time. When following aircraft, an FAA air traffic controller could change the array beam direction instantaneously through computer and electronic control. In one mechanical scan, the scanning technique can evaluate the array in many directions at once. Otherwise, using the conventional techniques, the array, electronic equipment and computer aboard a costly rotatable platform require rotation for measurement in each direction.

With the extrapolation technique, NBS scientists evaluate high-gain antennas for space missions, satellite communications and reference antennas for evaluating much larger antennas. Using this method, it is also possible to evaluate antennas for infrared and light waves.

Wacker is also developing a near-field spherical technique for evaluating fields over spherical surfaces in front of large dishshaped antennas used in studying microwave signals from outer space. It's difficult to design a measuring probe which moves 60 to 90 meters in the air above a 30- to 60-meter-diameter antenna. Wacker says he has licked both this problem and a monumental data reduction problem. With a fixed probe mounted above the antenna, he says he can determine the fields on a spherical surface in front of the antenna by moving the antenna on its mounting beneath the probe.

A Final Word

The NBS breakthrough in microwave antenna measurements on the scenic mesa range, in the laboratory and on actual antenna sites assures mankind better space-age communications. It has contributed to successful microwave antenna designs for Apollo and Sky-Lab missions, satellite communications systems and aircraft and shipboard radar. In space missions, these NBS techniques can reduce costly antenna failures and the bulkiness and cost of transmitters and receivers.

An effective and economical microwave antenna system saves users dollars and cents and conserves energy. For instance, microwave antennas can beam signals in a narrow path across millions of kilometers to earth or just across town. In earth-bound systems, NBS' precise antenna measurement techniques can help lower production and design costs, conserve valuable resource materials and reduce unnecessary energy consumption in microwave telecommunications. □

HOW BIG *continued*

Russia and M. C. Pontikis is working on a G project in France. In the United States, at NBS in Gaithersburg, Md., there is a Big G experiment under the direction of Richard Deslattes. There, Gabriel Luther and William Towler are using equipment originally devised in 1965 by physicist Jesse Beams of the University of Virginia.

The Koldewyn-Faller experiment started 4 years ago at Wesleyan University in Middletown, Conn., where Koldewyn was a graduate student and Faller was on the faculty teaching and doing research. They came to Boulder in 1972, bringing their experiment with them for completion at JILA.

Cavendish-Style Apparatus

Their apparatus is basically a refinement of the Cavendish experiment—with some important differences.

The small masses are 5-centimeter (2-inch-) diameter aluminum-oxide spheres joined by a 2.5-cm- (1-in-) diameter quartz tube about 27 cm (11 in) long. A magnesium clamp connects the midpoint of the quartz tube to a perpendicular ferrite rod. The whole assembly is symmetrical about the axis of the rod within .00025 cm (1 ten-thousandth of an inch).

Before being installed in the apparatus, it was mounted in air bearings and balanced in the same manner as the balance wheel of a fine watch.

This small-mass assembly, instead of simply deflecting toward the large masses as in the Cavendish experiment, will oscillate like a double-ended pendulum in a horizontal plane between the large masses.

The large masses are doughnut-shaped, machined, bronzed bearings built to support a ship's propeller shaft. These were readily available in Middletown because of the large dry-dock industry there, and they met the criteria of high density, sym-

metry and proper size. Still more importantly, the doughnut shape creates a region of uniform gravitational fields which greatly diminishes the demand for precise positioning of the pendulum between them.

The pendulum is suspended by a frictionless, torsionless magnetic bearing. Electric current to the supporting electromagnet is servo-controlled to maintain a 1-millimeter (.04-in) gap between the rod and the ferrite core of the magnet.

The pendulum operates in a vacuum chamber. Readout data are obtained through a window in the chamber by autocollimating light off a mirror on the pendulum assembly.

Pendulum is the Key to G

The whole apparatus is shielded from the magnetic field of the earth by giant helmholtz coils.

Unfortunately there is no way to shield against the earth's gravitational field. The vertical component of the earth's gravity is effectively cancelled by the pendulum's magnetic suspension, but, there is still the horizontal component to deal with. The laboratory is two stories underground so there is earth on all sides. However, with the large mass of the Rocky Mountains on the west, the principal horizontal gravitational gradient has an east-west orientation. Without the large bronze masses in place, the pendulum will oscillate in that orientation with a period of about 3 to 4 hours.

During the experiment, the bronze masses are placed in the same east-west configuration and the oscillation period decreases to 2 to 3 hours. The earth component must be determined and subtracted from the data to get the true figure for the masses of the apparatus itself.

It is by measuring the periods of the pendulum and processing it with other experimental data that Koldewyn and Faller expect to improve the measurement of G to at least a part in 10,000. □



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